Renewable Polymers and Advanced Materials

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Agriculture's role in providing a secure food supply is widely recognized as a priority. However, emerging trends indicate an increasing role with respect to renewable energy and materials. Growth rates in the renewable-energy and biobased-materials industries could exceed 20% per year over the next decade. Along with significant industry activity in this emerging bioeconomy, numerous initiatives are underway, involving research institutions across the United States.

Ohio BioProducts Innovation Center

The Ohio BioProducts Innovation Center (OBIC), initiated in 2005 with an award from Ohio's Third Frontier Program, integrates academia and industry in the development of renewable specialty chemicals, polymers/plastics and advanced materials. The Center is a new research alliance that operates on a market-pull business model designed to link core-research capabilities in genetics, biotechnology, chemical conversion and product development towards the commercialization of bioproducts that represent value propositions to industry members. This enabling research alliance builds on the strength of two of Ohio's largest industries: agriculture and the chemicals, polymers, plastics and rubber materials sectors. A board of advisors, established with the award to provide advice and feedback on basic management structure and policy, includes representatives of the Archer Daniels Midland Company, Ashland, Battelle, Cargill, Cooper Tire, Hexion, Ohio Corn Growers Association, Ohio Farm Bureau Federation, Ohio Soybean Council, Ohio Polymer Strategy Council, Owens Corning, PolyOne Corporation, Proctor and Gamble, Scotts, Sherwin-Williams, The Andersons, The Ohio State University, PolymerOhio, and USDA's Agricultural Research Service.

OBIC's scientists are focused on development of research and commercialization projects that are designed to address specific needs of industry. Projects are not limited

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to those of the industry members on the advisory board. The Center leverages industry involvement with extensive core research capabilities at Battelle, the Ohio State University, and the University of Akron. Linkages have been established with the US Department of Energy (DOE), National Renewable Energy Laboratory (NREL), Pacific Northwest National Laboratory (PNNL), Oak Ridge National Laboratory (ORNL) and US Department of Agriculture national labs.

Bioeconomy Drivers

As a major manufacturing state, Ohio is a significant user of energy and materials. These materials include chemicals and polymers that are typically combined to create advanced materials such as composites. In fact, it is estimated that chemicals, polymers, and advanced materials are integral components in 90% of all manufactured goods produced in Ohio. From 1999 to 2005, the production of chemicals, polymers, and advanced materials in Ohio increased over 15% (combined). Currently ranked #1, Ohio's polymer industry looms large in the state's economy both in dollar value of products exported and number of people employed. Leading business sectors within the polymer industry include paints and coatings, plastics, adhesives, detergents, and rubber.

Chemicals, polymers, and advanced materials are capital-intensive and rely heavily on petroleum in three significant ways: as a raw feedstock material, as energy for production, and as fuel to transport products to their destinations. Approximately 98% of all chemicals are derived from petroleum and natural gas (Frost, 2005). Relative to petroleum refining in the United States, economic viability is related to the value created by a portfolio of goods and services derived from petroleum. In fact, the petroleum-refining business is built on the basis of an integrated approach to allow flexibility and mitigate risk. Approximately 67% of petroleum goes to the transportation-fuel sector whereas only 7% is utilized in the chemical and polymer sector (Fig. 1). However, the latter sector has a 7-fold greater value.

Representatives from public- and private-sector groups supported by DOE and USDA established a target that the portion of plant/crop-based renewable resources addressing chemical and material needs will grow to 50% by 2050 (Fig. 2), the main drivers for which are volatility of fossil-based resources and potential impact of plant biotechnology. Global consumption of oil will increase in these and other emerging economies by 57% over the next 15 years. Fossil-based resources are finite, and many competitors are more strategically located than are major petroleum and natural gas reserves. New biotechnology is now enabling the development of oils, proteins, and carbohydrates with targeted functionality to produce value-added adhesives, coatings, polymers, composites, and other industrial products with differentiated properties and performances. In a 2000 McKinsey report, biotechnology is projected to make biopolymers cost-competitive with their petroleum-based counterparts by 2010 to 2015 (Bachman *et al.*, 2000). Furthermore, scientific and market research projects that biotechnology-based products will capture as much as 50% of the polymer market and 15% of the basic chemical market as a result of cost competitiveness as well as novel functionalities that have potential to revolutionize material applications.

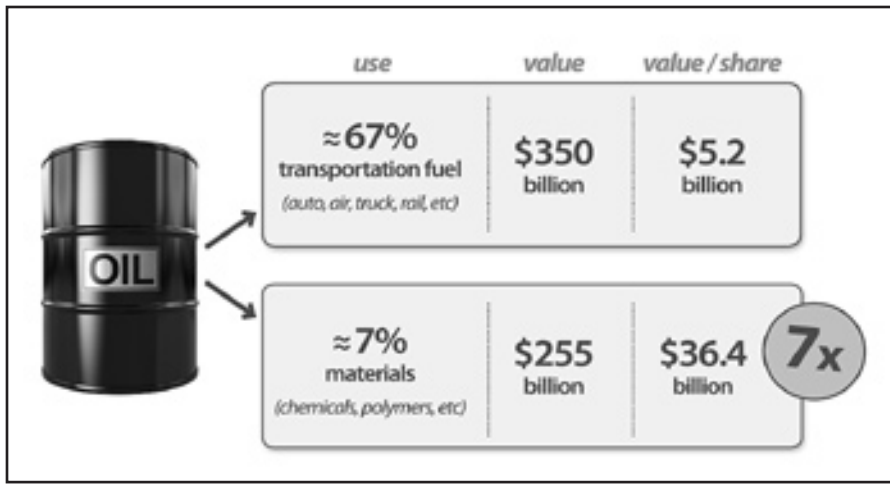

Figure 1. US petroleum market (Frost, 2005).

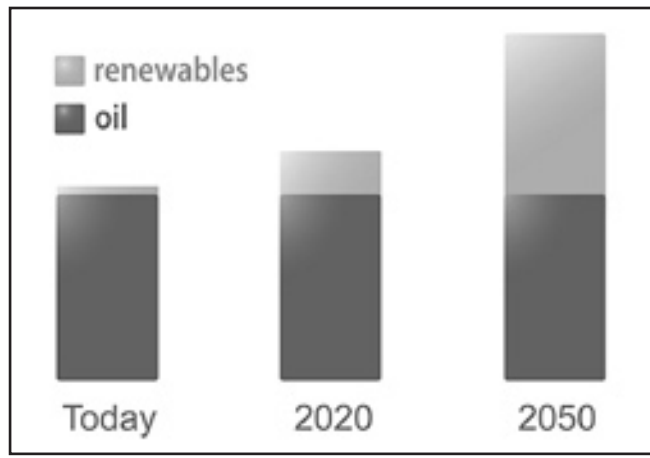

Figure 2. Targets to meet projected global material needs (ESG, 1999).

Ohio's Contributions

In an independent study, biopolymers were projected to be a major source of innovation for Ohio's polymer and advanced materials industry (Battelle, 2004). Based on a 2005 study, polymers and agriculture are two of the seven major industry sectors driving the economy in Ohio (CSU *et al.*, 2005) The convergence of new technologies (*i.e.* biotechnology, nanotechnology) at the intersection of these industry sectors is opening doors to innovations that could revolutionize nearly every aspect of our lives, from industrial manufacturing to production of chemicals and consumer goods and even environmental protection.

Ohio's agricultural bioscience industry is well positioned to take advantage of these emerging materials-based opportunities. In a recent study documenting Ohio's commercial bioscience industry, agricultural biotechnology was the largest economic sector (BioOhio, 2007). Recent analysis indicates that the state's food, agriculture and natural resource cluster generated approximately $93 billion in economic output, approximately 12% of the state's total output. This added 10% to Ohio's gross state product accounted for over a million Ohio jobs (15% of total state employment), and was responsible for 10% of total income. The state's employment concentration in agricultural processing is almost twice the national average, making agricultural processing in Ohio significantly specialized. While this industry is currently focused on food production, the presence of a bioprocessing infrastructure complements the potential development of additional valued-added uses of agricultural feedstocks for renewable energy and biomaterials. In fact, economic sustainability of biorefineries will likely be enhanced with an integrated approach with which biomass feedstocks are converted to a range of goods and services including food, materials and energy.

Ohio's agricultural industry has the potential to utilize substantial biomass resources, many of which are currently underutilized and offer significant value-added opportunities for conversion to biobased energy and materials. Ohio State University Professor Fred Hitzhusen (Jeanty *et al*., 2004) recently completed a research assessment of Ohio's biomass resources in the following categories:

- crop residues,
- wood biomass,
- livestock manure,
- municipal solid waste, and
- food processing waste.

Ohio is nationally ranked as eleventh in total amount of biomass potential. However, this ranking is thought to be higher due to the fact that detailed data are currently not available on food processing waste, which is significant given that Ohio ranks fourth nationally in total food-processing production.

Strong linkages between industry and research are fostering a research and development portfolio that will form the foundation for the emergence of a biobased chemicals industry centered on key Ohio technical assets with the capacity to:

- enhance genetic design capability to create novel building blocks,
- develop fundamental processes and products related to materials, and
- demonstrate and commercialize technologies and products through the Ohio polymer and materials industry.

Gaining full advantage of emerging biobased materials and integrating them into useful products will require a wide breadth of high-level research and application development with close collaboration among engineers, chemists, physicists, and biologists. Multifaceted partnerships in research and commercialization of integrating biobased polymers and new applications involving academia, industries, government, and national laboratories can

emerge optimally and most rapidly when there is a focal driver for the needed synergies and leveraging the respective capabilities.

Currently, OBIC alliance members are involved in a number of major initiatives. Soy-based industrial applications are being developed and commercialized by efforts of the Ohio Soybean Council through their support of research at Battelle and the Ohio State University. Ashland has established a leadership position with a new family of soy-based resins. The Program of Excellence in Natural Rubber Alternatives seeks to develop a domestic source of natural rubber and includes Ohio State, Oregon State, University of Akron, and USDA as well as leading rubber-industry leaders including Cooper Tire, Bridgestone and Goodyear. The Advanced Natural Fiber Composites initiative has established a consortium of academic and industry collaborators to commercialize breakthrough technology developed by the Natural Fiber Composites Corporation.

In Conclusion

Energy and materials are integral components of Ohio's economic future. While Ohio will continue to depend on fossil-based sources for energy and materials, developing alternatives may mitigate risk as well as provide sources of innovation and economic growth. Ohio is well-positioned to capitalize on emerging opportunities associated with the bioeconomy as related to biobased energy and materials. Ohio's strategic assets include strong polymer and agricultural industries, comprehensive supply chains and logistics, extensive research capabilities, abundant natural resources, and prime location.

As the bioeconomy develops to complement fossil-based sources of energy and materials, it will be imperative that efforts focus on areas where there is a strong value proposition for consumers. Likewise, an integrated refinery approach inherent to the petroleum industry is highly relevant to biobased energy and materials. Similarly, economic sustainability of biorefineries will likely be enhanced with an integrated approach where biomass feedstocks are converted to a range of goods and services including food, energy and materials (Fig. 3). With the appropriate balance of public/private effort, Ohio has the potential to achieve a leadership role in the emerging bioeconomy, particularly in respect to materials.

Throughout human history, agriculture has been a source of food, fuel and fiber. Opportunities have arisen unexpectedly and often through external events and trends that impacted patterns of production and utilization. While agriculture's role in providing a secure food supply remains the priority, emerging trends indicate increasing roles in terms of renewable energy and materials that will catalyze innovation as well as mitigate risks associated with over-dependence on imported fossil fuels. Growth rates in the renewable energy and biobased materials industries could exceed 20% per year over the next decade, creating significant economic opportunities. These opportunities will involve intersections of the agriculture, materials and energy sectors, as well as integration of emerging technologies, such as biotechnology, nanotechnology and bioinformatics. These advances will not be limited to technological innovation within the biological, physical and mechanical sciences. Societal values, government policy, environmental stewardship and economic drivers will, in great part, govern the extent of society's utilization of new technologies. Strong public/private collaborations involving multidisciplinary approaches

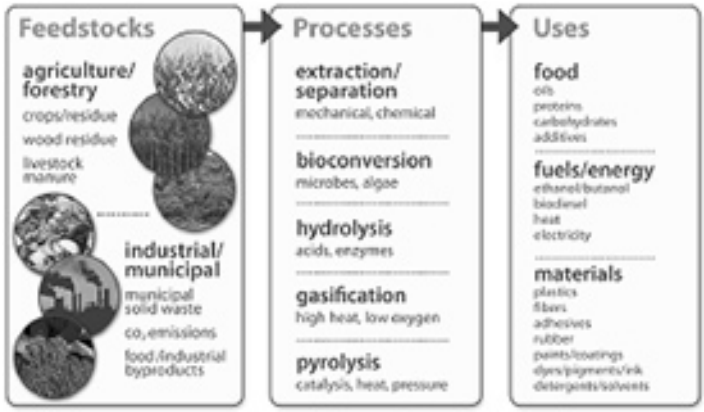

Figure 3: Integrated bioeconomy of feedstocks and products.

will be necessary to develop an integrated bioeconomy that addresses the food, fuel and fiber needs of society in a more sustainable manner. Given the complexity of this challenge, significant opportunities exist for institutions in research as well as in training the next generation of leaders for the bioeconomy.

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STEPHEN MYERS is assistant director of the Ohio State University's Ohio Agricultural Research and Development Center and director of the Ohio BioProducts Innovation Center. The latter is a research venture funded by Ohio's Third Frontier Program, integrating academia and industry for the development of renewable specialty chemicals, polymers/plastics and advanced materials. The venture builds on the strength of two of Ohio's largest industries: agriculture and the chemicals, plastics and rubber materials sector.

The Center leverages significant core-research capabilities at the Ohio State University, including the Ohio Agricultural Research and Development Center, the Molecular and Cellular Imaging Center, the Plant Biotechnology Center, the Center for Advanced Polymers and Composite Engineering, and the Center for Advanced Processing and Packaging Studies. With major leadership from the Battelle Memorial Institute, Center alliance members include the Archer Daniels Midland Company, Cargill, Cooper Tire, The Andersons, Hexion, Polymer Ohio, National Renewable Energy Lab, Oak Ridge National Lab, Ohio Corn Growers Association, Ohio Farm Bureau Federation, Ohio Soybean Council, Ohio Polymer Strategy Council, Owens Corning, Pacific Northwest National Lab, PolyOne Corporation, Proctor and Gamble, Scotts, Sherwin-Williams and USDA's Agricultural Research Service.